Evolution of Late Cretaceous ammonites and bio-events in the Russian Pacific

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2010

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Chapter 7. Mid-Late Cretaceous Bio-Events

7.1. Introduction

Kauffman (1986; see also Kauffman *et al*., 1996 and others) demonstrated that mass extinction events ranked amongst the most important correlative tools in global bio-events. He presented the Western Interior of North America as an example of the various types and levels of bio-events, their probable causes as well as their importance to high-resolution regional and global correlations. Since 1996 the same principles have been applied to the Cretaceous of the Russian Pacific coast in an attempt to demonstrate that, in spite of the high degree of faunal endemicity and provincialism , there are possibilities for global correlation (see, amongst others, Noda & Matsumoto, 1998; Zonova & Yazykova, 1998; Yazykova, 2004). The general trends in ammonite evolution (or in any biotic group, for that matter) in the boreal Pacific are the same as elsewhere (Yazykova, 1996, 2002, 2004). Bio-event by Bio-event (and/or zone-by-zone) changes in morphotypes and ecosystems in total are closely comparable to those observed in other regions, because it is assumed that the organic world is largely dependent of the global rules which govern local environments. Kauffman (1977) did not consider the Russian Pacific and Japan as regions characterised by high endemicity. In fact, data for the Western Interior (Kauffman, 1986) are the most closely comparable to the present results.

In a recent paper, Paul & Lamolda (2009) argued that bio-events based on first (FAD) or last appearance (LAD) datums sometimes may not be recognisable in all sections, not even within one region, in particular when these events are based on a single taxon. In addition, whenever recognisable, they may turn out to be diachronous. Such data support the proposal of present work for a revised global correlation by:

- 1) a choice of regional key sections and production of detailed biostratigraphic schemes based on different faunal groups with precise regional correlation (using some regional stages or horizons);
- 2) determination in regional key sections of all known types of biotic and abiotic events;
- 3) global correlation on the basis of both biostratigraphic zonation and events from one to another key sections with final trend to GSSP section.

A regional key section for Sakhalin was described from the south of the island in the valley of the River Naiba. For northeast Russia there are three areas where key sections should be accepted, but only after proper documentation of events: the Penzhyna Gulf Coast

(partially described in Zonova, 2006), the Koryak Upland (partially described in Dundo *et al*., 1977) and Chukotka Peninsula, inclusive of the Chukotka Upland (not described to date).

Below **a** brief description for some of the regional bio-event levels recorded for each (sub)stage in Russian Pacific sections is presented.

7.2. Regional Bio-Events compared to allegedly global events (Fig. 7.1)

All bio-events recorded on the Russian Pacific coast are compared to those from other regions in the world, which have often been assumed to be global in nature, but, with some exceptions, have not yet been studied in detail.

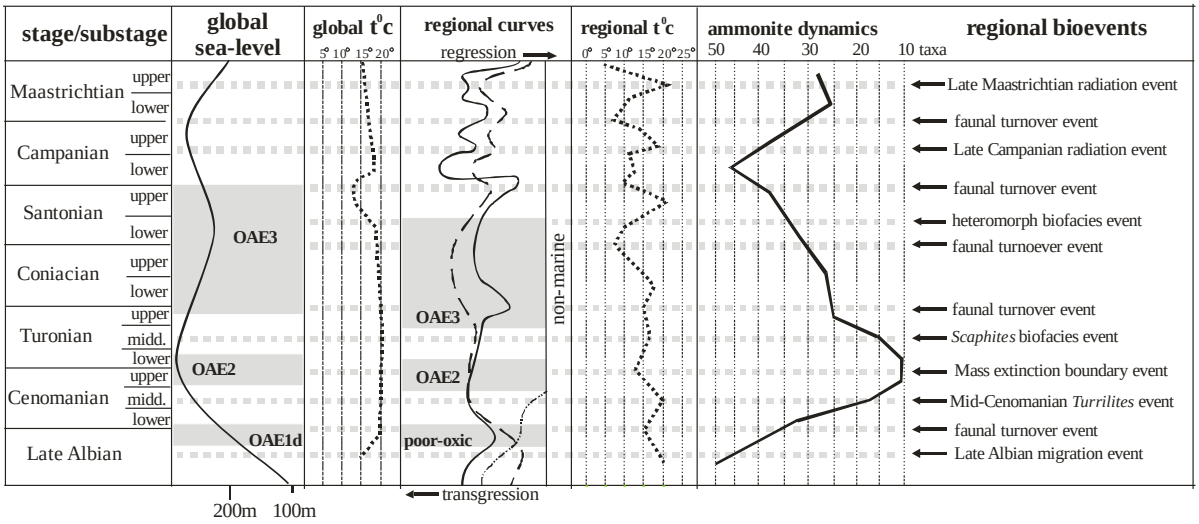

Fig. 7.1. Regional bioevents recorded in Far East Russian regions and changes of total number of species of the mid- and Late Cretaceous ammonites in the Russian Far East (Yazykova, present paper); global sea level curves by Haq*et al*. (1988), global palaeotemperature curves (Skelton, 2003), regional palaeotemperature curves modified after Zakharov*et al*. (1996, 1998, 2006); generalised scheme of records of transgression and regression from Sikhote Alin (red line), Japan, Sakhalin (black line) and NE Russia (blue line) palaeobasins based on Matsumoto, 1980), stages are shown without calibration to absolute time.

7.2.1. Late Albian migration Bio-Event

The late Albian migration event is best recognised in the Russian Far East in upper Albian sediments of Sikhote Alin and northeast Russia. The basin which existed in Sikhote Alin during late Albian-early Cenomanian time was inhabited by ammonites of both Tethyan and Boreal realms, as were Sakhalin, Japan and northeast Russia, plus taxa which are never found in all three regions at the same time (Zonova & Yazykova, 2000, 2001, 2004). The Sakhalin palaeobasin is characterised by a rather taxonomically poor complex of ammonites in comparison to Sikhote Alin and northeast Russia, but in total the late Albian ammonite assemblage shows the maximum diversity (Fig. 7.1).

A closely similar pattern has been outlined (Amédro & Robaszynski, 2005) for northern California where the succession yielded both exotic ammonites of the Tethyan realm (e.g.,

Oxytropidoceras and *Lyelliceras*) as well as taxa from the Boreal realm (*Gastroplites*, *Pseudopulchellia*). Those authors discussed possible correlations by ammonites between the Albian sequences of northern California and European and Arctic provinces. A succession of confinement periods, with numerous endemic faunas, followed by periods of open communications and the appearance of cosmopolitan forms was determined. Amédro & Robaszynski (2005) concluded that the stratigraphic distribution of Albian, non-endemic ammonites of northern California and Europe was largely controlled by global eustatic events and showed some possible ways of migration for endemic forms.

Probably the late Albian migration event is linked to the middle-late Albian bio-event that has been recorded from North America, Europe, India and North Africa and which is characterised by short-term extinctions among ammonite genera and species, especially in northern temperate faunas (e.g., *Gastroplites*, *Pseudopulchellia*) and warm-temperate subtropical taxa (e.g., *Oxytropidoceras* and *Lyelliceras*) connected with OAEIb and OAE1c (Barnes *et al*., 1995). Thus, those ammonites which disappeared in the regions mentioned could have migrated into more marginal areas such as California, northeast Russia, Sakhalin and Sikhote Alin during the late Albian.

7.2.2. Albian/Cenomanian bioevent - global faunal turnover event

The Lower/Upper Cretaceous boundary is marked by a complete disruption of links between the Pacific and European realms and, coincidently, between the Boreal and Tethyan realms. From the early Cenomanian onwards, the Far East Russian region can be divided into a southern and a northern Pacific province. During the Late Cretaceous, the northern Pacific province may be described generally as Boreal (Far East Russia, Alaska, Japan, California, Queen Charlotte Islands), whereas the southern Pacific province is Tethyan (New Zealand, Australia). The palaeobasin of Primorje and Sikhote Alin emerged during the Cenomanian.

An abrupt faunal turnover marks the Albian/Cenomanian boundary. In the Russian Pacific, with the exception of two species, all Albian taxa disappeared at this boundary. A short-term, global turnover in marine biota following OAE1d (Barnes *et al*., 1995) characterises this level in many regions of the world (Fig. 5.16). The OAE1d (Figs 5.14, 5.16) has been recorded from Japan and Sakhalin as well (Hirano & Takagi, 1995; Hasegawa, 1997; Hirano & Fukuji, 1997; Toshimitsu & Hirano, 2000; Hasegawa *et al*., 2003). The disappearance of Albian forms and the first occurrence of new species and even genera as well as of new morphotypes amongst ammonites and inoceramids is also typical of this boundary in the Pacific Realm.

7.2.3. Mid-Cenomanian *Turrilites* event

Representatives of *Turrilites costatus* and *T. acutus* are known from middle Cenomanian deposits of Sakhalin Island and the Penzhyna Gulf coast, as well as from the Koryak Upland (Vereschagin *et al*., 1965; Terekhova & Mikhailova, 1977) and Japan (Hayakawa & Nishino, 1999; Shigeta, 2001; Matsumoto & Takahashi, 2001). These two levels could possibly be correlated with the so-called mid-Cenomanian Regressive Trough (*Turrilites costatus* event) and the mid-Cenomanian eustatic low (*Turrilites acutus* records), respectively (Hancock, 2003). This eustatic lowstand has been recorded from northwest Europe, western Kazakhstan, Texas, Colorado and South Dakota. Monnet & Bucher (2007) proposed the last occurrence of *T. acutus* as a marker for the middle/upper Cenomanian boundary since that species was also abundant and widely distributed. This marker is useful in Sakhalin as well as for northeasterly regions of Russia.

7.2.4. Cenomanian/Turonian boundary extinction bio-event

At the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995), it was recommended that the main criterion for the Cenomanian/Turonian be the first appearance datums of the ammonites *Watinoceras devonense* Wright & Kennedy (see Bengtson, 1996). Kennedy *et al*. (2000, 2005) have suggested the first occurrence of the inoceramid *Mytiloides puebloensis* Walaszczyk & Cobban for the base of the Turonian. Neither of these species has been recorded from Far East Russia. A single specimen has been noted from the upper Cenomanian in Japan, as *Watinoceras* (?) sp., but with the remark, 'somewhat questionable' (Toshimitsu & Hirano, 2000, p. 580).

The first detailed analysis of correlation between Turonian sequences in Japan and those in northwest Europe was performed by Hancock, Kennedy & Wright (1977), who demonstrated the numerous difficulties that arose during attempts to determine any possible correlative criteria on the basis of appearance and/or disappearance of zonal indexes.

The Cenomanian/Turonian boundary remains one of the best-studied mass extinctions in the world and is a perfect event-correlative level, albeit occasionally with its own specific character in each biogeographic province and region. Recently, a first attempt to analyse that bio-event in Sakhalin has been carried out (Yazykova *et al*., 2004; see Chapter 2 here). No Cenomanian taxa survived this crisis, neither in Sakhalin nor in northeast Russia. Correlation is based on association with OAE2 (Fig. 5.14), the appearance of the ammonite genera *Fagesia* and *Jimboiceras* and the inoceramid *Mytiloides*, thus the appearance of new

ammonite morphotypes in general. Kauffman (*in* Barnes *et al*., 1995) referred to this bio-event as the most dynamic, second-order, stepwise mass extinction during a sea level highstand. The disappearance of the *Pergamentia*-group amongst inoceramids in Far East Russia (see Chapter 2 here; Yazykova *et al*., 2004) can be correlated with the extinction of the *Inoceramus pictus* group in European areas and/or the Western Interior of North America (Kennedy & Cobban, 1991; Harries *et al*., 1996; Kauffman & Harries, 1996; Kennedy *et al*., 2000) as well as western Siberia (Khomentovsky *et al*., 1999; V.A. Zakharov *et al*., 2003). This could be used as an additional criterion for this boundary.

7.2.5. Mid-Turonian *Scaphites* biofacies event

The criterion recommended at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) for the lower/middle Turonian boundary, namely the FAD of *Collignoniceras woollgari* (Mantell) **(**Bengtson, 1996) cannot be accepted in the Russian Far East, because this species has not been yet found there. Meanwhile, *C. woollgari* and some other representatives of this genus have been found in Japan. So, probably, these taxa may also be demonstrated in future to occur at least in Sakhalin, which was in close proximity to the Japanese islands, or, alternatively, *C. woollgari* just did not migrate further than Japan. This is coincident with other differences in the taxonomic composition of macrofaunal complexes from Sakhalin and Japan, which also could be explained by the appearance of temporary biogeographical barriers between these two areas.

The wide distribution of heteromorph ammonites, particularly the development of the *Scaphites* facies in the upper lower-mid Turonian, was recorded from numerous regions in the world, occurring at the same level (Tanabe, 1979; Kaplan *et al*., 1987; Hirano *et al*., 2000). In Far East Russia, numerous representatives of *Scaphites* co-occur with species of the genera *Nipponites* and *Hyphantoceras* (see Chapter 2; Vereschagin *et al*., 1965; Mirolubov *in* Poyarkova, 1987; Zonova & Yazykova, 1998; Yazykova *et al*., 2004). The *Scaphites* facies is one of the best global correlative levels. However, in the northwest Pacific at the same level appeared another heteromorph genus, *Scalarites*. In fact, this would be a good criterion for the lower-middle Turonian boundary here.

7.2.6. Middle-Late Turonian boundary Bio-Event

The regression at the end of the Turonian in Russian Pacific basins is marked by the appearance of trachyostracans, i.e. coarsely ornamented ammonites, and heteromorphs, indicative of relatively shallow waters (Tanabe, 1977; Westermann, 1996). However, the taxonomical diversity of ammonites decreased at this level (Fig. 7.1).The warm, shallow-marine basin was conducive to inoceramid development, a group which showed a high diversity during the boundary interval (Zonova & Yazykova, 1998). Numerous small-sized inoceramid species occur in the lower/upper Turonian boundary interval (*Inoceramus teshioensis, Mytiloides incertus* Zone in Sakhalin and *Inoceramus multiformis* Zone in northeast Russia) (see Chapter 5, section 5.7.4 and Zonova & Yazykova, 1998). Usually, all inoceramid species which appeared in the lower and middle Turonian are of average size typical of most inoceramid species. In the uppermost Turonian all of them are small and numerous. Usually fossil taxa in the immediate aftermath of mass extinction events are much smaller compared to those of pre-extinction assemblages – the "Lilliput effect" (Harries & Wani, 2009). In the study area, there is a level just prior the next faunal turnover at the Turonian/Coniacian boundary. This level is traceable from northeast Russia to Sakhalin and Japan, and possibly could be correlated with the *waltersdorfensis* II Event in the upper Turonian of Germany and Poland (Walaszczyk & Wood, 1998), which is also characterised by the occurrence of small-sized inoceramids of the *waltersdorfensis* group. Bivalves are very sensitive ecologically and the presence of small-sized inoceramids could both signify a mass extinction and environmental changes such as higher salinities or temperature.

7.2.7. Turonian/Coniacian faunal turnover event

The main criteria for the recognition of the Turonian/Coniacian stage boundary proposed at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995), such as the first occurrence of *Forresteria* (*Harleites*) *petrocoriensis* for Europe and of *F. peruana* and *F. brancoi* for North America and the first occurrence of *Cremnoceramus rotundatus* (*sensu* Tröger, 1967, *non* Fiege, 1930) (see Kauffman *et al*., 1996), which is now referred to as *C. deformis erectus* (Meek, 1877) (compare Walaszczyk & Wood, 1998; Walaszczyk, 2000) cannot be applied to the Russian Pacific because the index species are absent. Moreover, it has been suggested that representatives of the genus *Forresteria* in fact make their first appearance in the uppermost Turonian (Kennedy & Cobban, 1991; Walaszczyk & Cobban, 2000; Kennedy & Walaszczyk, 2004). This means *Forresteria* can no longer be used as an index for the base of the Coniacian, leaving the first occurrence of

Cremnoceramus deformis erectus as the sole criterion (Kauffman *et al*., 1996; Walaszczyk & Wood, 1999; Walaszczyk & Cobban, 2000).

So far, in Russian Pacific sections, only a single specimen of *Forresteria* has been collected from the upper part of the Coniacian sequence there (Mirolubov *in* Poyarkova, 1987). This boundary in Russian Pacific sections is based on some local criteria, i.e. the LAD of *Jimboiceras planulatiforme* and the FAD of *J. mihoense* (see section 7.1.1.4), as well as on the first occurrence of *Anagaudryceras politissimum* and *Gaudryceras denseplicatum*. Also, the base of the Coniacian is marked by the occurrence of a new *Scaphites* assemblage (endemic species) in Sakhalin and northeast Russia, similar to Europe (Kauffman & Hart, 1995; Kauffman *et al*., 1996).

In North America, as well as in Europe (Kauffman & Hart, 1995), this bio-event is marked, first of all, by the loss of the cosmopolitan *Mytiloides* inoceramid group lineage and the widely distributed ammonite genus *Prionocyclus*. These inoceramids are replaced by the *Cremnoceramus erectus* group, and amongst ammonites, *Peroniceras* is a newcomer.

The appearance of various representatives of the *Inoceramus uwajimensis* group marked the base of the Coniacian in the Russian Far East and Japan together with *Peroniceras* which ousted *Subprionocyclus* and *Jimboiceras mihoense* replacing *J. planulatiforme* (Zonova & Yazykova, 1998). That event may be coincident with the mass occurrence of inoceramids of the *Volviceramus* group in western Siberia (Khomentovsky *et al*., 1999; V.A. Zakharov *et al*., 2003) and with the *Cremnoceramus erectus* fauna (Walaszczyk & Wood, 1999; Walaszczyk, 2000) in Europe. *Inoceramus uwajimensis* Yehara is probably a vicariant species of *Cremnoceramus erectus* (Meek).

Approximately at the lower/upper Coniacian boundary interval, another radiation of new species of the heteromorph ammonite genera *Scaphites*, *Scalarites* and *Nipponites* is noted and in total the taxonomical diversity increased (Fig. 7.1). Probably this bio-event could be put forward to characterise the lower/upper Coniacian boundary, after it has been properly documented from other regions. All of these mentioned taxa disappeared at the end of this stage in the Russian Pacific.

7.2.8. Coniacian/Santonian faunal turnover event

The exact position of the Coniacian/Santonian boundary is still very problematic in the Russian Far East (Yazykova & Zonova, 2002) as well as in Japan (Toshimitsu *et al*., 2007).

The first appearance of the ammonite genus *Texanites* was rejected as the main marker for this boundary at the Second International Symposium on Cretaceous Stage Boundaries

(Brussels, 1995). The prime marker recommended there, i.e. the FAD of *Cladoceramus undulatoplicatus*, cannot be applied in Far East Russia, nor in Japan. Isolated occurrences of *Inoceramus* sp. aff. *Cl. undulatoplicatus* are known from the upper Santonian of Sakhalin, co-occurring with *I.* (*Platyceramus*) *kawasakii* (Zonova *et al*., 1993). The Coniacian/Santonian boundary in Japan is situated at the limit between the *Inoceramus uwajimensis-I. mihoensis* and the *Inoceramus amakusensis* zones, which is equated with the base of the *Texanites collignoni-T. quinquenodosus* Zone (Toshimitsu *et al*., 2007).

In western Siberia, a mass occurrence of species of the inoceramid genus *Sphenoceramus* was recorded from the lowest Santonian, together with *Oxytoma tenuicostata* (Roemer) (Khomentovsky *et al*., 1999; V.A. Zakharov *et al*., 2003).

The FADs of *Inoceramus amakusensis* and *Texanites* (*Plesiotexanites*) *kawasakii* are the two best criteria for the base of the Santonian Stage in Sakhalin (see Chapter 3; Yazykova, 1996, 2002), in spite of the fact that both are endemic. However, lending support to this interpretation is the co-occurrence of these taxa with the cosmopolitan ammonites *Desmophyllites diphylloides* and *Phyllopachyceras forbesianum*. The former is widely distributed in the Santonian-Campanian, with records from Oman, southern India, North Africa, Western Australia, North America (inclusive of the Western Interior), southern Argentina, Angola, Pondoland and ?Madagascar (Collignon, 1969), as well as the Campanian of Corbières (southern France) and Crimea (Henderson & McNamara, 1985; Kennedy, 1995; Arkadiev *et al*., 2000; Klinger *et al*., 2001). The latter appeared in the Pacific and later extended in the Santonian to lowermost Maastrichtian of Alaska, Spain (Bay of Biscay), southern India, Madagascar, British Columbia (Jones, 1963), California, New Zealand, Western Australia, Antarctica, Argentina, northern Germany, Austria, Galicia (Henderson, 1970; Ward & Kennedy, 1993) as well as the Maastrichtian of northeast Mexico (Ifrim *et al*., 2004) and central Chile (Salazar, pers. comm.., 2009).

Correlation problems again might be resolved by refined studies of bio-events. The gradual decrease in ammonite and inoceramid taxonomic diversity, as observed in the Coniacian succession and possibly triggered by a renewed regression and a slight temperature drop (Yu. D. Zakharov *et al*., 1996, 1998), came to a halt at the beginning of the Santonian. The Coniacian/Santonian faunal turnover, characterised by the same evolutionary trends, has been documented from many places across the globe (Kauffman & Hart, 1995; Hallam & Wignall, 1997).

7.2.9. Late Santonian heteromorph biofacies event

Near the lower/upper Santonian, macrofaunal taxonomical diversity increased again, linked to a global sea level rise and an increase in temperature. New taxa, representing new morphotypes, appeared, especially new genera of heteromorphs. This bio-event could be proposed for the lower/upper Santonian boundary as soon as it has been documented in detail from regions elsewhere.

7.2.10. Santonian/Campanian faunal turnover event

None of the criteria recommended at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) for Santonian/Campanian boundary, i.e. the extinction of the crinoid genus *Marsupites,* the FAD of the ammonite *Placenticeras bidorsatum* and the belemnite *Gonioteuthis granulataquadrata* (see Hancock & Gale, 1996), is applicable either in Sakhalin, northeast Russia or Japan, because the taxa in question have not been recorded from these areas.

The Santonian/Campanian boundary in Sakhalin as currently marked by the first appearance of the inoceramid bivalve *Inoceramus nagaoi* Matsumoto and the ammonite *Anapachydiscus* (*Neopachydiscus*) *naumanni* (see Chapters 3 and 4 here; Yazykova, 2002; Yazykova *et al*., 2002); these two criteria are also applicable in Japan (see Fig.5.12; compare Toshimitsu *et al*., 1995). Additionally, the base of the Campanian can be defined, both in Sakhalin and adjacent Hokkaido (Matsumoto, 1977a; Toshimitsu *et al.*, 1995), by the LAD of *Texanites* and the FAD of *Phyllopachyceras ezoense* (see Chapter 6 here; Yazykova, 1996, 2002).

Vishnevskaya & Basov (2007) recorded a mass extinction event amongst radiolarians at the Santonian/Campanian boundary and the appearance of new taxonomic assemblages in the lowest Campanian in the sections along the Russian Pacific coast and compared this bio-event with other regions in the world. Recent magnetostratigraphic analyses for Sakhalin, Hokkaido, Shikoku, the Western Interior and California (Kodama, 2003) show a good match across the Santonian/Campanian boundary, as well as for two levels within the Campanian.

The bio-event of near-total disappearance of inoceramids at the S/C boundary, occurs in western Siberia. There is just a single record of *Inoceramus nagaoi* Matsumoto & Yeda from the basal Campanian, which is a criterion in Sakhalin, northeast Russia and Japan and an explosion in taxonomic diversity of dinocysts in the upper water levels (Khomentovsky *et al*., 1999; V.A. Zakharov *et al*., 2003) and anoxia close to the sea floor. It seems that in many other regions Campanian assemblages of marine dinocysts are diverse and abundant (see for

example Soliman *et al*., 2009), while assemblages of different macrofaunal groups (see Chapter 4; Yazykova, 1996, 2002, 2004) occur in the early survival period following the S/C biotic crisis.

7.2.11. Lower/upper Campanian radiation bio-event

A distinct level of faunal radiation recorded across the lower/upper Campanian boundary (see section 4.4.2, Yazykova *et al*. (2002)) is traceable from northeast Russia, through Sakhalin and Japan, and into Europe, for example, in southern Poland (author's data, unpubl.). In the Russian Far East this level is marked by the onset of a shallow-water facies with abundant ammonites, new morphotypes of inoceramids, new taxa of gastropods and non-inoceramid bivalves. The highest diversity is found amongst benthic groups, and some planktonic forms are associated. Representatives of some biotic groups form coquina-like beds. In southern Poland, in sections in the Miechów area the lower/upper Campanian interval is marked by a regressive hardground surface and the lower Campanian is characterised by an abundance of fossils (Jagt *et al*., 2004). The biotic event(s) at the lower/upper Campanian level in different regions of the world may constitute a good correlative marker level, but need further study.

Schmidticeramus schmidti is known from the upper Santonian of Alaska and British Columbia (recorded under the name of *Sphenoceramus schmidti* by Haggart *et al*., 2009 [see Chapter 3]). It is the main constituent at this upper Campanian level along the western Pacific coast. However, on the other side of the Pacific, *S. schmidti* occurs in the upper Santonian together with another species of radially ribbed inoceramid and different ammonites, forming coquina beds. Again, it is not possible to correlate on the basis of this taxon only, but one has to consider the entire complex of biological and lithological features. The level described from British Columbia and Alaska may be correlative with the *Hoplitoplacenticeras vancouverense* Zone (Ward, 1978; Haggart *et al*., 2009).

The lower/upper Campanian boundary can be recognised in other groups as well, e.g. vertebrates (mosasaurs), which appeared in many regions at this level, so that there is evidence of a wide-ranging biotic event throughout the water column, from plankton to the top of the food chain (Lindgren, 2004; Jagt, 2005). Vishnevskaya (2009) noted remarkable taxonomic changes in early and late Campanian radiolarian associations, which may reflect environmental changes within the palaeobasins of Sakhalin, the Koryak Upland and Kamchatka.

During Campanian time, a general reduction in taxonomic diversity amongst heteromorphs is typical of Russian Pacific regions.

7.2.12. Campanian/Maastrichtian faunal turnover event

The first occurrence of *Pachydiscus* (*P.*) *neubergicus* (von Hauer, 1858), the marker for the C/M boundary (Brussels, 1955), cannot be applied in Sakhalin. The few finds from the Russian Far East (Vereschagin *et al*., 1965; Zonova *et al*., 1993; Yazikova, 1994), stem from upper Maastrichtian deposits. It is possible that the Pacific specimens are either not conspecific with *P*. (*P*.) *neubergicus* and previous identifications are erroneous or that they are in fact conspecific but appeared in the Pacific much later. Alternatively, there is also the possibility of misidentification and it could be that these finds from the Russian Pacific actually belong to different species (A. Alekseev, pers. comm.., 2004). A revision of all specimens from Sakhalin, the Koryak Upland and Kamchatka that have been labelled *Pachydiscus* (*P.*) *neubergicus* and *P.* (*P.*) *gollevillensis*, with detailed comparisons with the holotypes of both principally European species is in preparation.

The FAD of *P.* (*P.*) *neubergicus* as definition of the base of the Maastrichtian was ratified by IUGS (Odin & Lamaurelle, 2001). Instead of using just a single faunal event, an arithmetic mean of twelve biohorizon levels is now employed, and level 115.2 at the quarry at Tercis les Bains (Landes, France) is the recommended level for placement of the GSSP for the boundary (Odin, 2001). None of these biohorizons (ammonites, dinoflagellates, planktonic and benthic forams, inoceramids and calcareous nannofossils) can be applied in Far East Russia. Calcareous nannofossils have not been recorded yet here and planktonic foraminifera are extremely rare and poorly preserved (Turenko *in* Poyarkova, 1987; Peryt *in* Yazykova *et al*., 2004; D. Peryt, pers. comm.., 2009).

However, there are biohorizons specific to the Pacific, marking a bio-event which is correlatable with the Campanian/Maastrichtian boundary in that area. First of all, there is the disappearance of most Campanian ammonite and inoceramid taxa, and the FADs of *Pachydiscus* (*P.*) *subcompressus* and *P.* (*Neodesmoceras*) *japonicus*. Both pachydiscids are widely distributed Pacific species (Yazykova 1991; Yazikova 1994, with references therein). This level is matched by a similar horizon in Japan (Toshimitsu *et al*., 1995). Moreover, this boundary can be recognised by the appearance of the inoceramid *Shachmaticeramus* (Zonova *et al*., 1993) characterised by a peculiar chess-board construction of the ligament strip.

7.2.13. Lower/upper Maastrichtian inoceramid extinction event and Late Maastrichtian ammonite radiation event

The lower/upper Maastrichtian boundary is marked by the worldwide demise of most inoceramid bivalve lineages (Ward *et al*., 1991; MacLeod, 1994), an abrupt extinction of rudistid bivalve-dominated reef ecosystems (Johnson & Kauffman, 1990) and a great reduction in the diversity of shallow, warm-water, level-bottom communities, the so-called 68 Ma Extinction Bio-Event *sensu* Kauffman & Hart (1995). Those authors also noted a general cooling and eustatic fall under way at this time (Kauffman & Hart, 1995, p. 301). Nifuku *et al*. (2009) described the stratigraphically youngest finds of *Pachydiscus (P.) flexuosus* and '*Inoceramus' awajiensis* Matsumoto from the lower upper Maastrichtian, around 300 m below the Cretaceous/Paleogene boundary in Japan. Based on those data, they claimed that the mass extinction of inoceramids and ammonites took place in the North Pacific 2.3-5.0 myr prior to the K/Pg boundary.

In the Russian North Pacific coast a decrease of inoceramid diversity is also recorded at this level; only a few new species appeared but their representatives are not numerous and the youngest amongst them have been collected from c. 100 m below the Cretaceous/Paleogene boundary in Sakhalin (Zonova et al., 1993). However, *Tenuipteria* (?) *awajiensis* and *Korjakia kociubinskii* Pokhialajnen have been recorded from the upper upper Maastrichtian in Sakhalin and Koryak Upland, respectively (Zonova *et al*., 1993; Pokhialajnen, 1988).

A bloom and radiation event for the ammonite families Pachydiscidae, Phylloceratidae and Gaudryceratidae marks the lower/upper Maastrichtian boundary in the Russian Far East, Phylloceratidae and Gaudryceratidae predominated and reached their maximum species diversity in the Late Cretaceous. Despite the fact that most early Maastrichtian forms disappeared during the late early Maastrichtian, possibly as a result of short-lived, subfreezing conditions which, as Yu.D. Zakharov *et al*. (2005) noted, could occasionally have occurred in the Northern Hemisphere, new species appeared at the base of the upper Maastrichtian (a temperature maximum was recorded here by Yu.D. Zakharov *et al*., 2005, see Fig. 7.1) and rapidly distributed across the entire northwest Pacific provinces, extending even to the northeast Pacific coast (Ifrim *et al*., 2004). That radiation was one of the fastest during the Late Cretaceous. The taxonomic diversity of ammonites reached levels of the upper Turonian (Fig. 7.1).

A migratory pathway must have existed between the western Tethys and the Pacific Ocean during Maastrichtian time, allowing faunal interchange through northeast Mexico and causing a mixture of cephalopod assemblages from different latitudes and an increase in

faunal diversity (Ifrim *et al*., 2004). Pacific ammonites (mostly from northerly regions) and the coleoid *Naefia neogaeia* were interpreted by Ifrim *et al*. (2004) as cold-water faunal elements, indicative of a minor cooling event in the northeast Pacific. The appearance in the upper Maastrichtian in Sakhalin of warm-water species such as *Brahmaites*, *Zelandites varuna* and *Pseudophyllites indra* may be indicative of a warming event. Of note, in this respect, is also the occurrence of *Diplomoceras cylindraceum* in the upper Maastrichtian of Far East Russia and Mexico, as elsewhere in the world.

However, the youngest ammonites in Sakhalin were found in the highest 1,5 metres below the 20-cm bed of green clay in the Sinegorsk Formation at the Naiba section, which represents the Cretaceous/Paleogene boundary in Sakhalin (Yazykova, 2004, section 5.7.8). Concretions from this level yielded well-preserved representatives of *Zelandites japonicus, Gaudryceras* sp., *Neophylloceras* sp. and *Tenuipteria* (?) *awajiensis*. This is the highest bed of concretions (a temperature minimum having been recorded by Yu.D. Zakharov *et al*., 2005, see Fig. 7.1); such beds occur comparatively regularly (every 2-3 m) in Member 5 of the Krasnoyarka Formation. The next youngest concretion layer, approximately 4-5 m below the K/Pg boundary, yields representatives of seven ammonite (sub)genera, i.e. *Pachydiscus (P.), P. (Neodesmoceras), Hypophylloceras (Neophylloceras), Gaudryceras, Anagaudryceras, Zelandites* and *Diplomoceras*. At the Zumaya (Spain) and Hendaye (France) sections (Wiedmann & Kullmann, 1996 with references), eight genera were recorded 15 m below that boundary, i.e. *Neophylloceras*, *Gaudryceras*, *Saghalinites*, *Pseudophyllites*,*Vertebrites*, *Anapachydiscus*, *Pachydiscus* and *Diplomoceras.* In the uppermost 0.5 m below the boundary at Zumaya, *Neophylloceras ramosum*, and at Hendaye, *Gaudryceras* sp., *Pachydiscus gollevillensis* and *P.* sp. have been recorded. In general, deep-water, long-lived phylloceratids and lytoceratids were dominant among the last ammonoids (Wiedmann & Kullmann, 1996). Probably, the extinction of these two long-lived stocks, which had survived various previous perturbations during the whole Cretaceous, left other groups highly vulnerable and prone to extinction as well.

7.2.14. Cretaceous/Paleogene mass extinction bio-event

Above the green clay bed in the Sinegorsk Formation at the Naiba section in Sakhalin, sandy mudstones yield a Danian fauna (spores and pollen, and bivalves; see Poyarkova, 1987). There are no ammonite finds known above this level in Sakhalin, nor are there in northeast Russia and Shikotan Island (Kuril Islands), where the last inoceramids and ammonites have been found in the Malokurilsk Formation. In Shikotan, the contact between

the Malokurilsk and Zelenovsk formations is considered to be the Cretaceous/Paleogene boundary but it has not been described in detail yet.

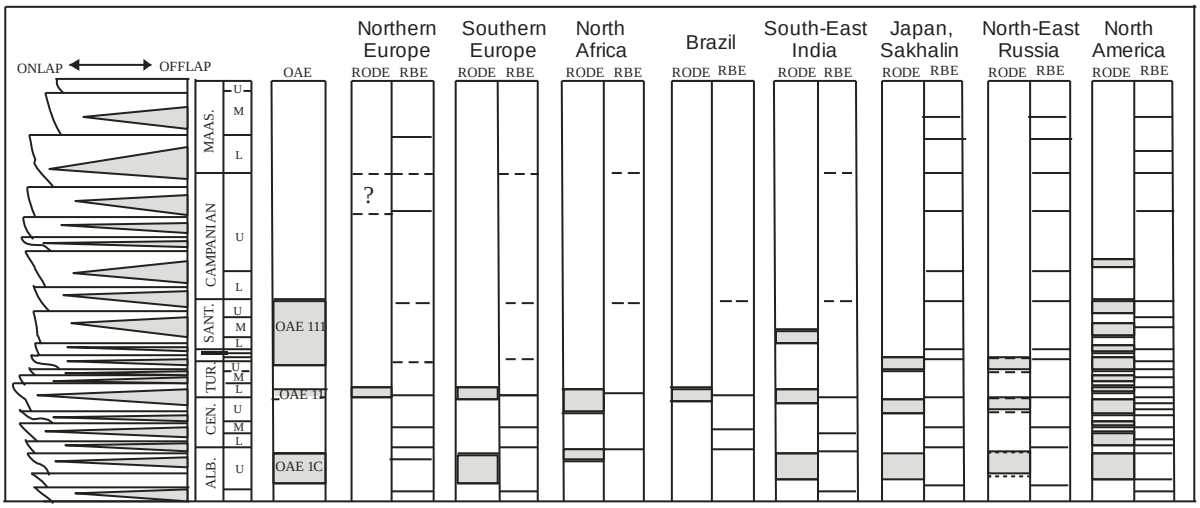

Fig. 7.2. Global cycle chart (Haq *et al*., 1987), together with global oceanic anoxic events (OAE), regional oxygen depletion events (RODE) and regional bioevents (RBE) in northern and southern Europe, North Africa, Brazil, southeast India, North America (modified after Kauffman & Hart, 1995) and Japan (Toshimitsu & Hirano, 2000), Sakhalin and northeast Russia (modified after Yazykova, 2004).

7.3. Conclusions

1. Endemicity and provincialism in the Pacific realm make determination of stage boundaries in Pacific sections difficult. Correlation with other areas (Europe, Mediterranean regions, Western Interior of USA, Pacific coast of North and South America, etc.) can only be resolved by using event stratigraphy. Not only extinction events but all biotic events or sometimes their combination of need to be considered.
2. The above-mentioned issues concern also other areas where it is difficult to find representatives of the proposed boundary criteria. This underscores the usefulness of the definition of local stages within local key sections, to improve the usefulness of the standard (GSSP) sections to many different areas across the globe. For example, the usage of New Zealand regional stages (alongside the worldwide stage names) is one such an example, as are the old Russian and Japanese stratigraphic subdivisions, now obsolete, but nevertheless highly useful (see Chapter 5 for more details).

3. A detailed analysis of ammonite evolution, based on mid- and Late Cretaceous sections from the Russian Pacific coast and a comparison with other provinces across the globe, fails to support a decreasing trend in ammonite diversity since the late Albian, as outlined in textbooks and numerous other publications (e.g., Kauffman, Hallam, Stanley, Wiedmann). On the contrary, ammonites displayed a high adaptive ability after each extinction event, and recovered from each event with new radiations.
4. During the mid-Late Cretaceous, fourteen regional bio-events were recorded and compared to those from other regions in the world (Fig.7.2): late Albian migration bio-event; Albian/Cenomanian bio-event - global faunal turnover event; mid-Cenomanian Turrilites event; Cenomanian/Turonian boundary extinction bio-event; mid-Turonian *Scaphites* biofacies event; mid-late Turonian boundary bio-event; Turonian/Coniacian faunal turnover event; Coniacian/Santonian faunal turnover event; late Santonian heteromorph biofacies event; Santonian/Campanian faunal turnover event; lower/upper Campanian radiation bio-event; Campanian/Maastrichtian faunal turnover event; lower/upper Maastrichtian inoceramid extinction event and late Maastrichtian ammonite radiation event; Cretaceous/Paleogene mass extinction bio-event.
5. The final demise of ammonites must have been sudden, i.e. catastrophic. Only a small number of species briefly extended into the Paleocene in some places (e.g., New Jersey, Denmark, the Netherlands). Possibly, the extinction of two such long-lived stocks as the phylloceratids and lytoceratids which had survived various previous perturbations during the whole Cretaceous, left other groups highly vulnerable and prone to extinction as well.